Jet fragmentation studies at LHCb

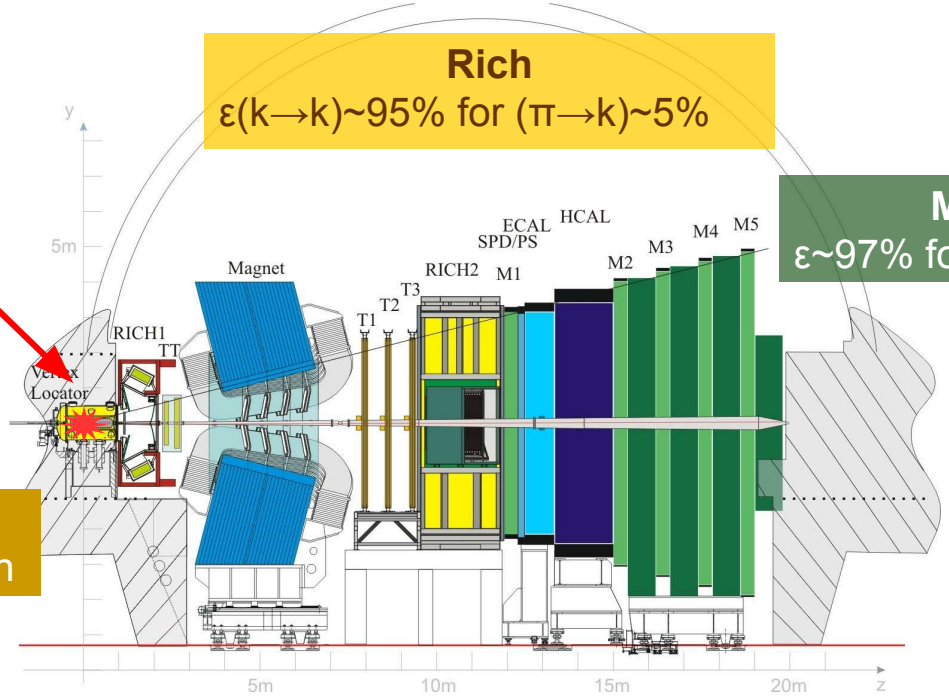
Murilo Rangel
on behalf of the LHCb Collaboration

lape
if Instituto de Física
Universidade Federal do Rio de Janeiro

LHCb is a single arm spectrometer fully instrumented in the forward region (2.0<η<5.0)
Designed for heavy flavour physics and also exploited for general purpose physics
[Int. J. Mod. Phys. A 30, 1530022 (2015)]

Rich
ε(k→k)~95% for (π→k)~5%

Collision



Muon
ε~97% for misID~2%

[more details in Giovanni's talk]

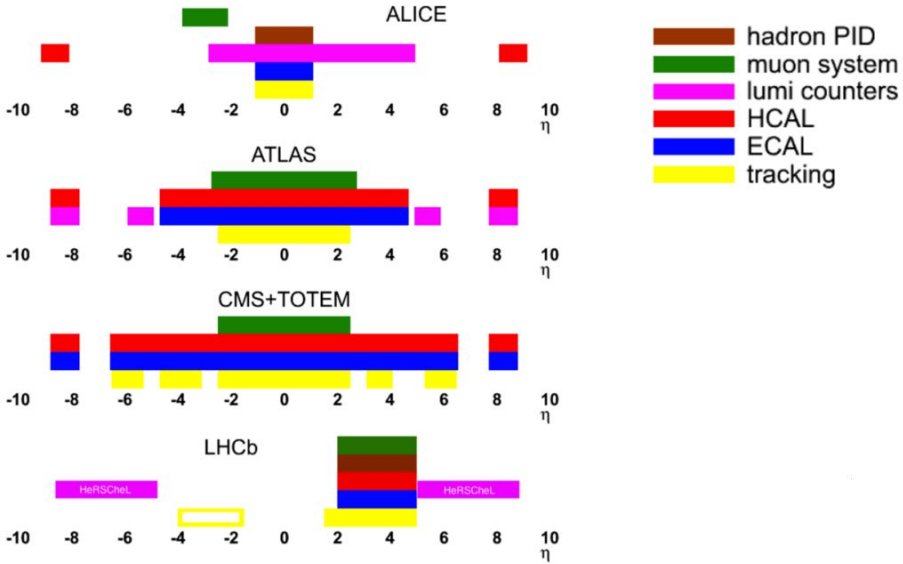
VELO
~20μm IP resolution

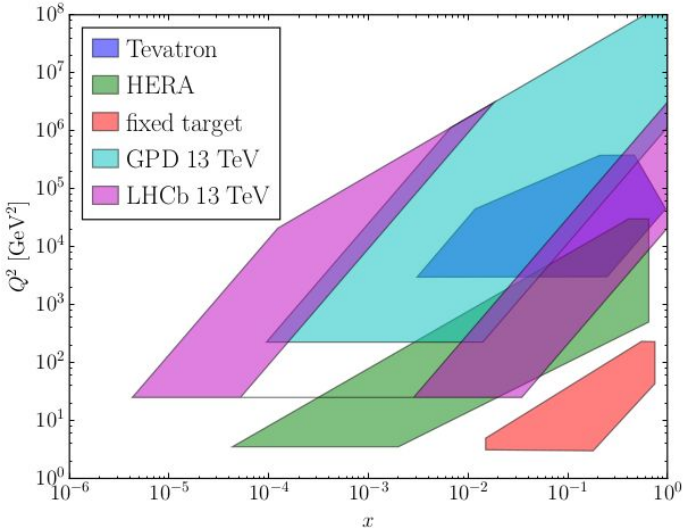
Tracking (magnet)
0.4%-0.6% momentum resolution (0.2-100 GeV)

LHCb advantages:

- unique kinematical coverage
- particle identification
- momentum and vertex resolution

$$\sigma = \int xfx(f_1, x_1, Q^2) xfx(f_2, x_2, Q^2) \hat{\sigma}\, \mathrm{d}x_1 \mathrm{d}x_2, \quad Q^2(x) = e^{\pm 2y} x^2 s$$





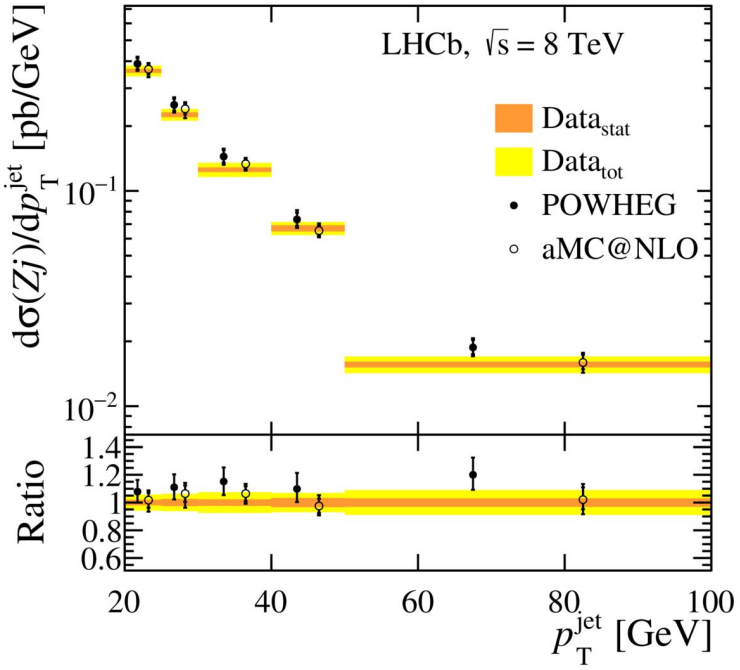
Charged hadron production in Z-tagged jets (Z+jets)

arXiv:1904.08878 [hep-ex] (submitted to PRL)

⇒ use Z($\rightarrow\mu\mu$)+jets events - 60 < $M_{\mu\mu}$ < 120 GeV and 2.0 < η_{μ} < 4.5

⇒ jets reconstructed with anti-kt algorithm (R=0.5)

JHEP 05 (2016) 131



Charged hadron production in Z-tagged jets

Analysis Strategy:

⇒ use Z($\rightarrow\mu\mu$)+jets events - 60 < $M_{\mu\mu}$ < 120 GeV and 2.0 < η_{μ} < 4.5

⇒ jets reconstructed with anti-kt algorithm (R=0.5) - p_T(jet) > 20 GeV and 2.5 < η(jet) < 4.0

⇒ $\Delta\varphi$(Z,jet) > 7π/8 - enhance 2→2 production

⇒ Use hadrons with p_T > 250 MeV and p > 4 GeV to measure the hadronisation variables

⇒ Correction and unfolding applied to calculate hadron production at particle level

$$z \equiv \frac{\mathbf{p}_{jet}\cdot\mathbf{p}_{hadron}}{|\mathbf{p}_{jet}|^2} \qquad j_T \equiv \frac{|\mathbf{p}_{jet}\times\mathbf{p}_{hadron}|}{|\mathbf{p}_{jet}|} \qquad r \equiv \sqrt{(\phi_{jet}-\phi_{hadron})^2+(y_{jet}-y_{hadron})^2}$$

Measurement of fragmentation functions:

Unique opportunity to study hadron production relative to an object that is correlated to the scattered parton

Questions about correlations between particles, universality, factorisation, and color-charge flow

arXiv:1904.08878 [hep-ex]

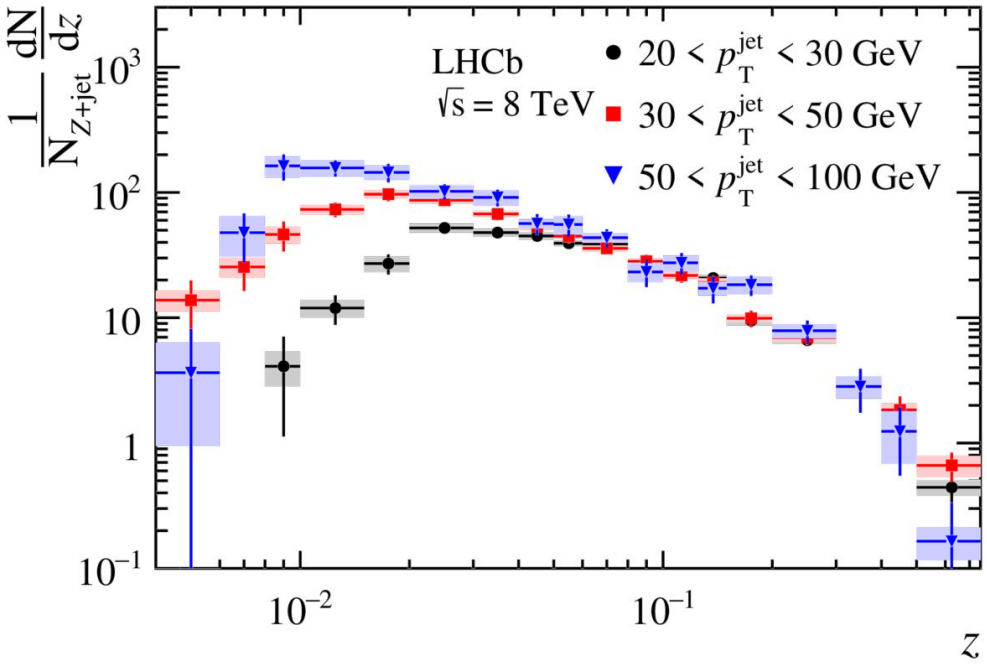
Charged hadron production in Z-tagged jets

Measurements in 3 jet p_T bins:

♯ independent of jet p_T at high z

♯ diverge at low z due to kinematic phase space available

$$z \equiv \frac{\mathbf{p}_{jet} \cdot \mathbf{p}_{hadron}}{|\mathbf{p}_{jet}|^2}$$



arXiv:1904.08878 [hep-ex]

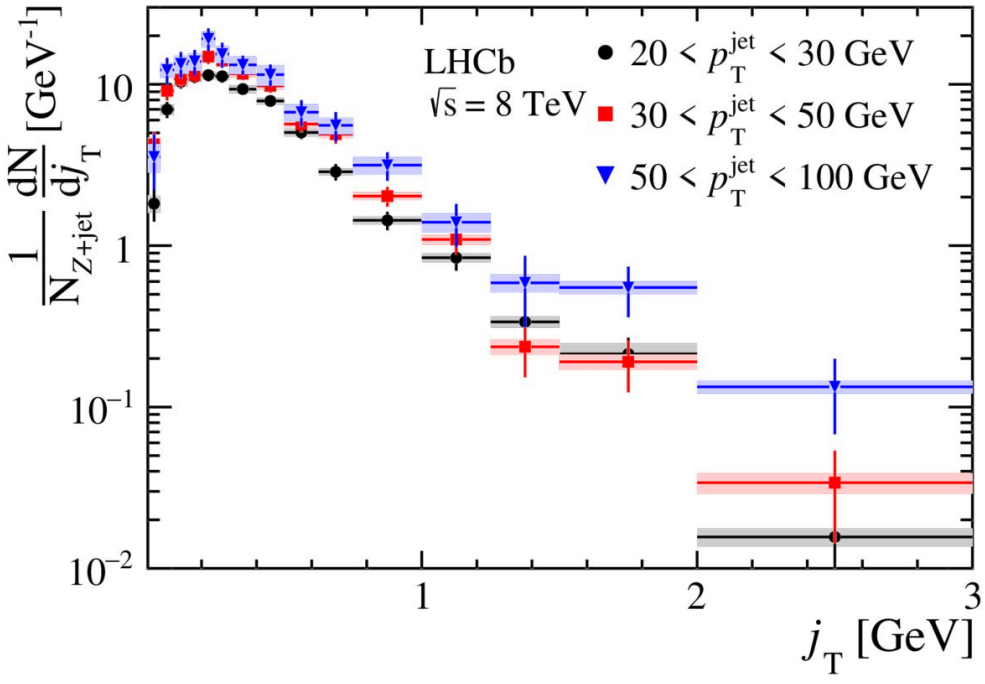
Charged hadron production in Z-tagged jets

Measurements in 3 jet p_T bins:

♯ nonperturbative shape at small j_T

♯ shapes are very similar, but slight increase at high jet p_T

$$j_T \equiv \frac{|\mathbf{p}_{jet} \times \mathbf{p}_{hadron}|}{|\mathbf{p}_{jet}|}$$



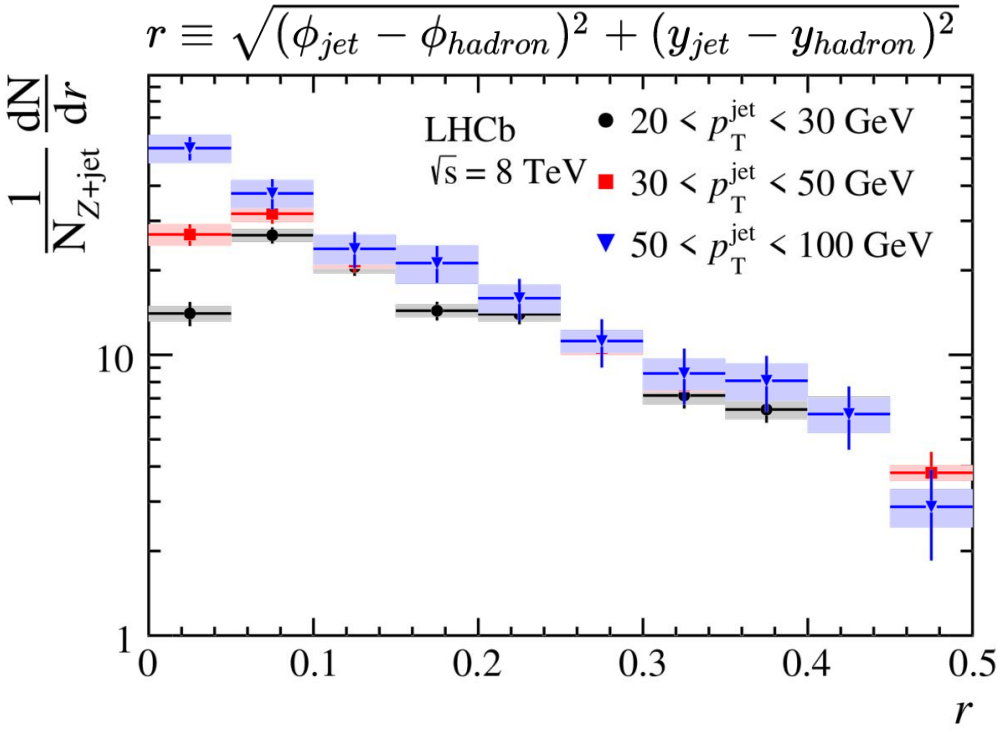
arXiv:1904.08878 [hep-ex]

Charged hadron production in Z-tagged jets

Measurements in 3 jet p_T bins:

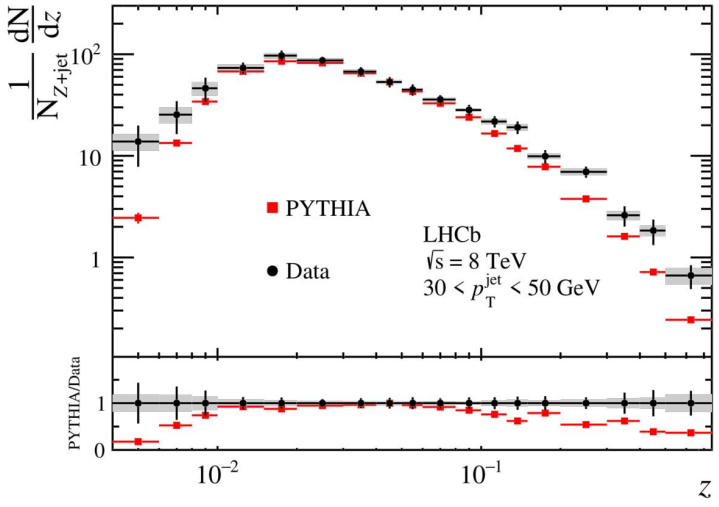
♯ radial profiles away from jet axis are constant as function of jet p_T

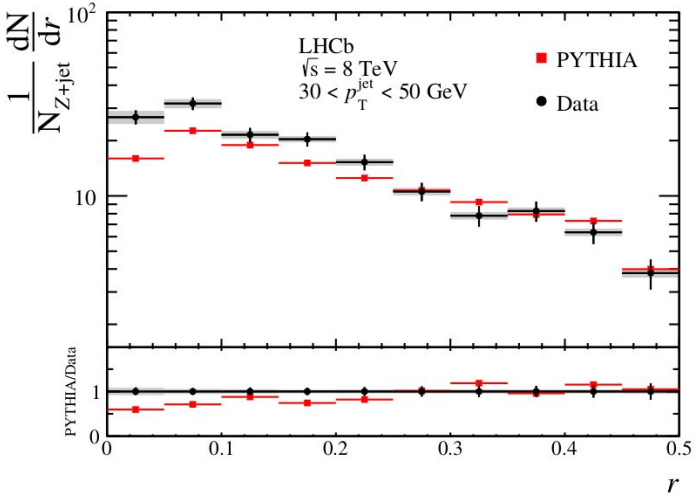
♯ radial profiles show that the number of charged hadrons at small *r* is highly dependent on jet p_T



arXiv:1904.08878 [hep-ex]

Charged hadron production in Z-tagged jets



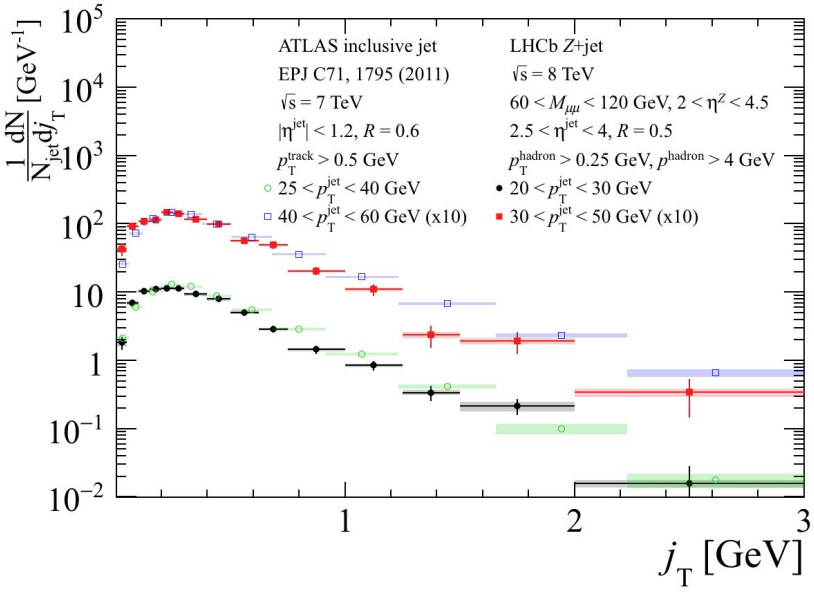


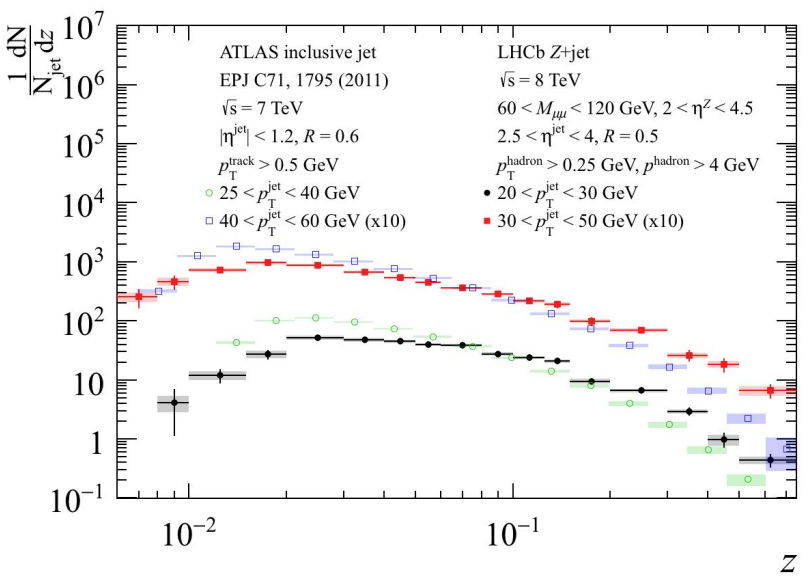
The fragmentation functions are also compared to predictions from Pythia Z+jet events

In general, Pythia underestimates the number of charged hadrons at high and low *z* and small *r*. Pythia also underestimates the number of charged hadrons in uniformly in j_T.

arXiv:1904.08878 [hep-ex]

Charged hadron production in Z-tagged jets





Comparison with central rapidities (inclusive jets dominated by gluon jets):

↣ The j_T fragmentation distributions are similar to the central pseudorapidity inclusive jet results

↣ The fragmentation functions are not as steeply falling at high z

Same conclusion for radial profile

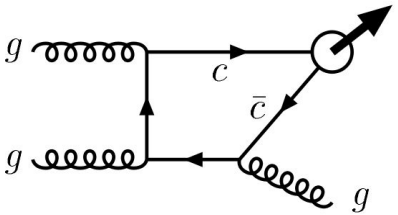
arXiv:1904.08878 [hep-ex]

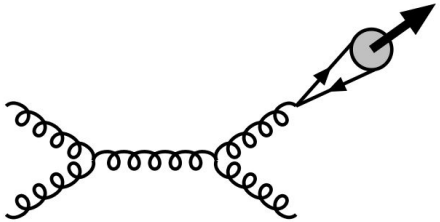
J/ψ production in jets

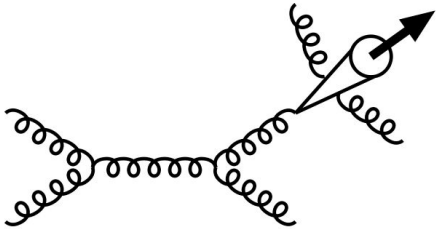
PHYS. REV. LETT.118.192001

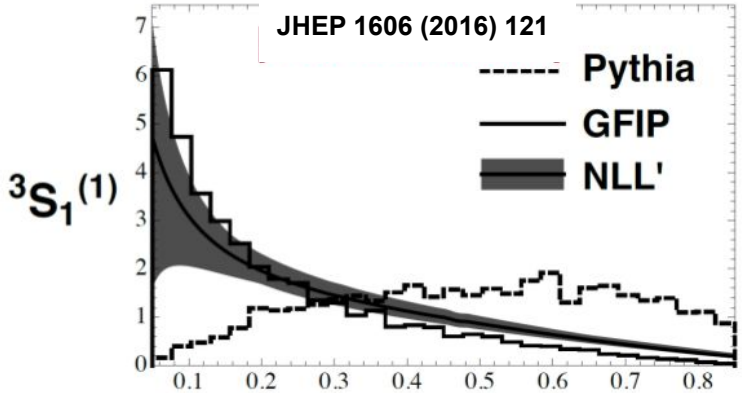
J/ψ Production at LHC:

- transition between the perturbative and non-perturbative regimes of QCD
- NRQCD-based calculations predict a large degree of transverse polarization
- direct-production paradigm: isolated or within jets









jet energy that is carried by the identified hadron

J/ψ in jets

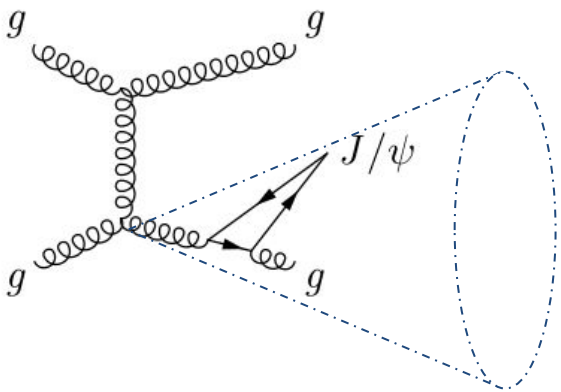
Analysis Strategy:

⇒ use J/$\psi(\rightarrow\mu\mu)$-in-jet candidates from inclusive muon trigger: $p_T(\mu) > 0.5$ GeV and $2.0 < \eta(\mu) < 4.5$

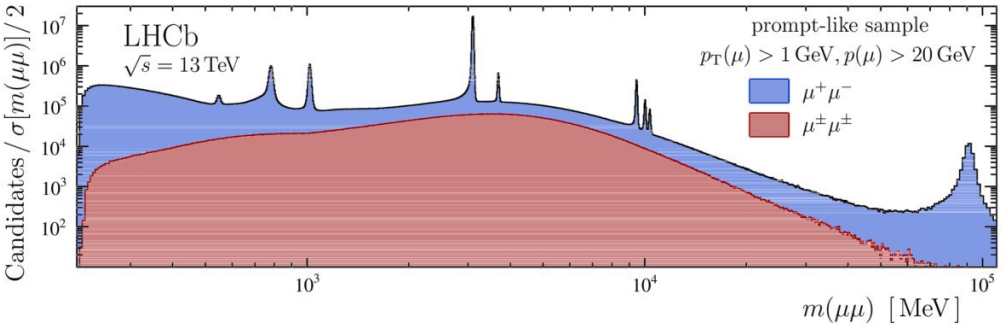
⇒ jets reconstructed with anti-kt algorithm (R=0.5) - $p_T(\text{jet}) > 20$ GeV and $2.5 < \eta(\text{jet}) < 4.0$

⇒ use fraction of the jet transverse momentum carried by the J/ψ meson

$$z(J/\psi) \equiv \frac{p_T(J/\psi)}{p_T(jet)}$$



Phys.Rev.Lett.120.061801

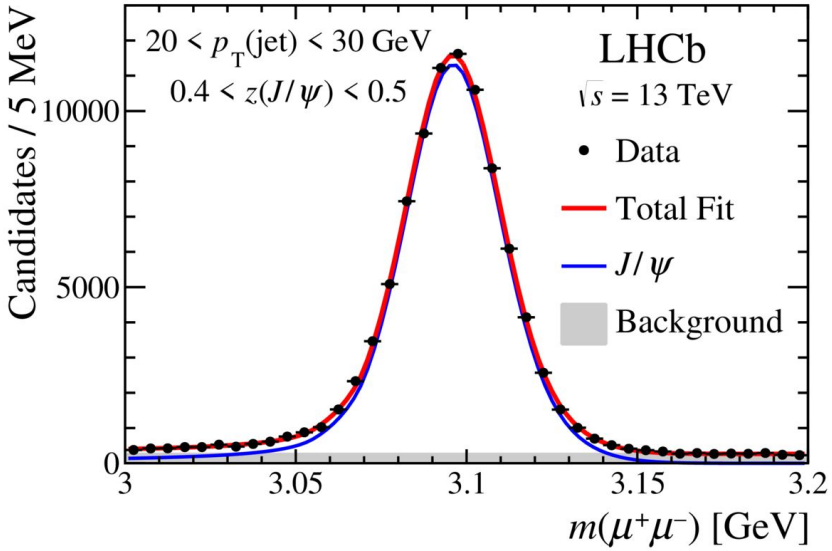


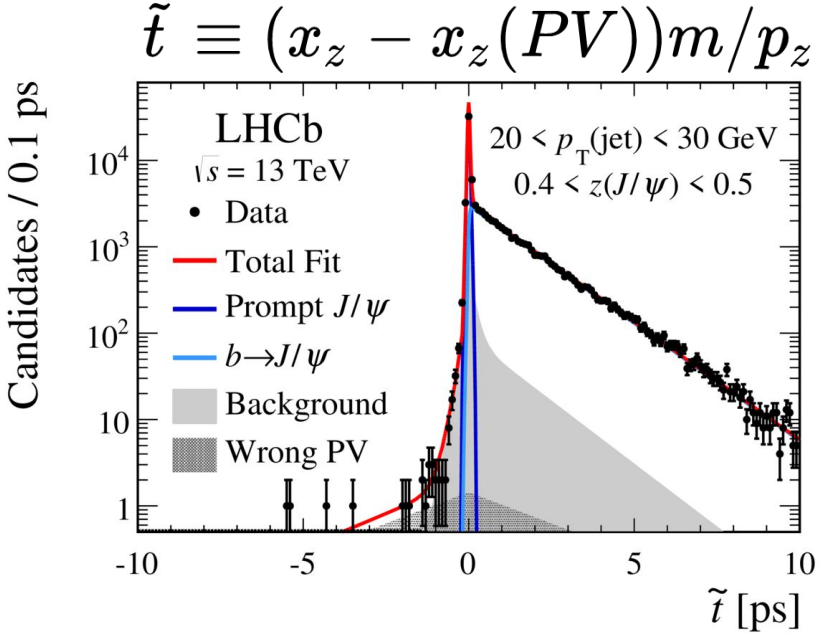
J/ψ in jets

Measurement:

⇒ determine J/ψ signal yield for each bin using mass fits

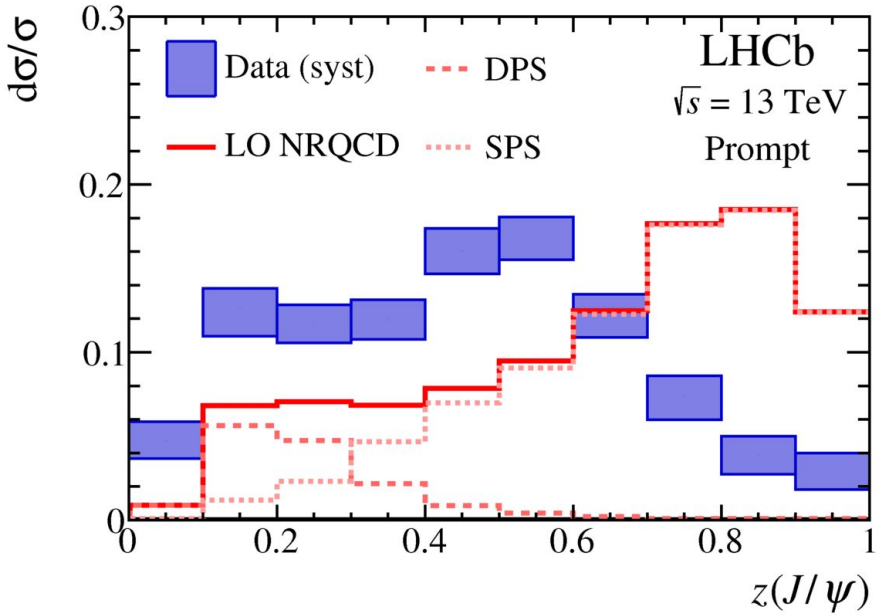
⇒ separate prompt from displaced (from b-hadron decays) using pseudo-lifetime fits

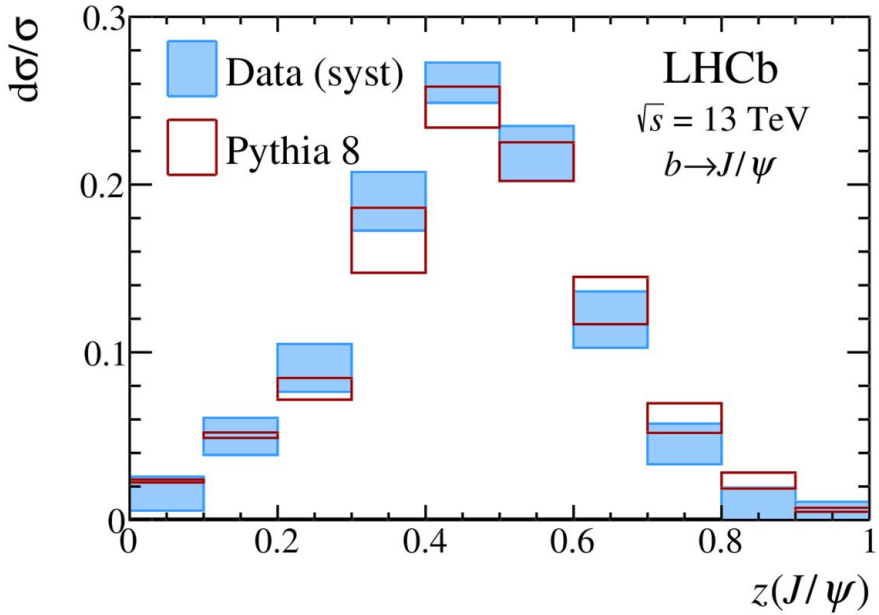




[Phys.Rev.Lett.118.192001]

J/ψ in jets





After efficiency correction and unfolding, distributions can be compared to predictions

- prompt results do not agree with LO-NRQCD prediction as implemented in Pythia 8
- b-hadron results are consistent with the Pythia 8 prediction

Phys.Rev.Lett.118.192001

Measurement of b-hadron fractions in 13 TeV *pp* collisions

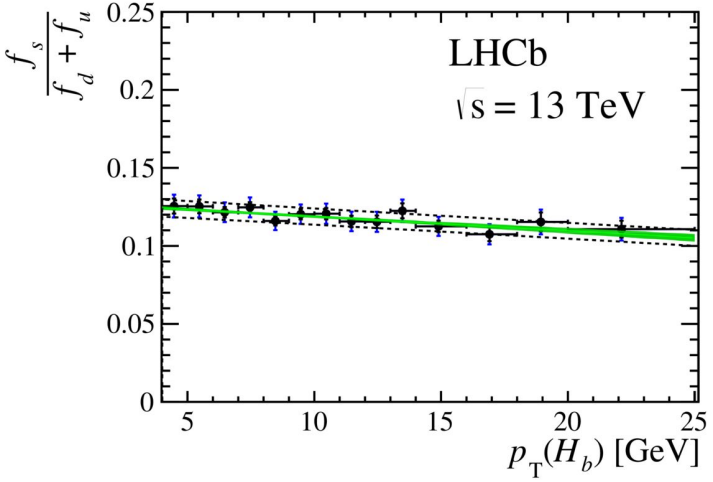
arXiv:1902.06794 [hep-ex] (submitted to PRL)

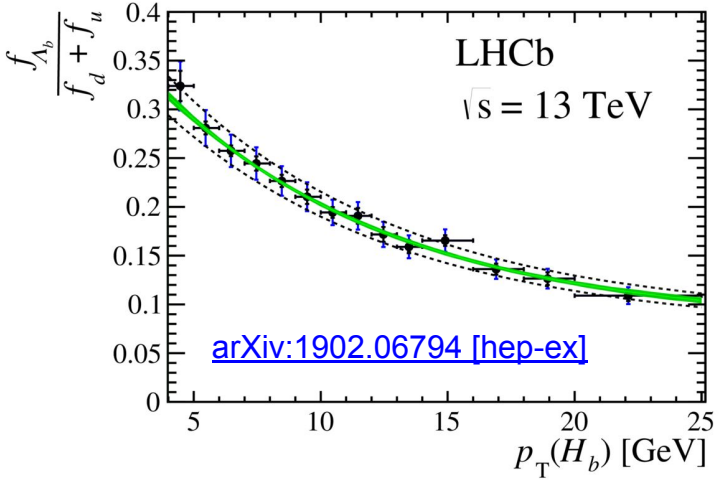
b-quark fragmentation fractions:

- essential for determining absolute branching fractions (ex: $B_s \to \mu\mu$)
- expected dependence on p_T and η

$$\frac{d\sigma^B}{dp_T^B} = \int dp_T^b \; dx \; \frac{d\sigma^{pp\to b\bar{b}}}{dp_T^b} \; \mathcal{D}_{b\to B}(x) \; \delta(p_T - x p_T^b)$$

perturbative — non-perturbative (not known from the first-principles)





Summary

★ Hadronization in Z -tagged jets

★ J/ψ in jets

★ Fragmentation fractions of hadrons

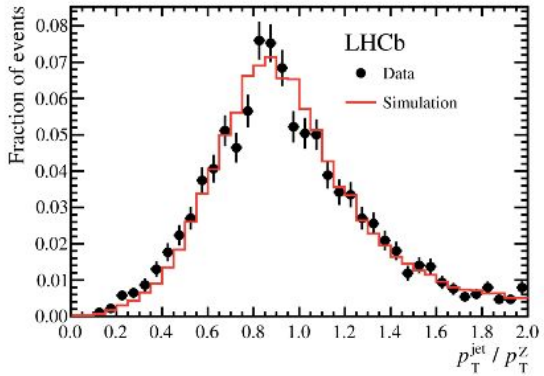
⇉ Great results to improve the knowledge of nonperturbative QCD

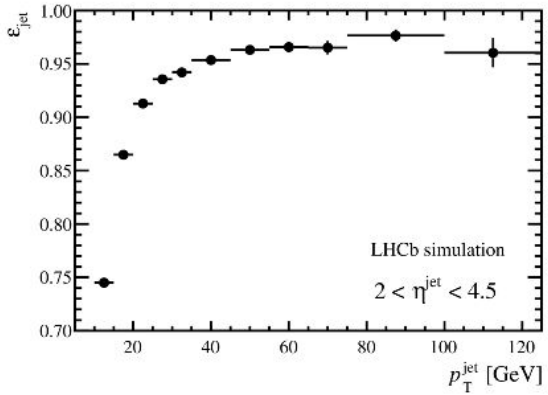
↠ Future measurements on-going and other related results can be found here

THANK YOU!

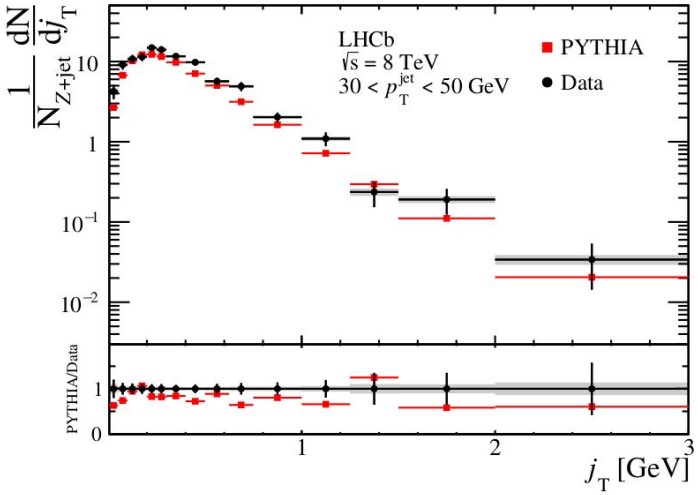
Particle Flow approach, with neutral recovery

- Jets reconstructed using anti-k_T
- R = 0.5
- Calibration in data, using $Z \rightarrow \mu\mu$ + jets
- Efficiency above 90% for jets with p_T above 20 GeV/c
- Jets reconstructed both online and offline!





JHEP01 (2014) 033



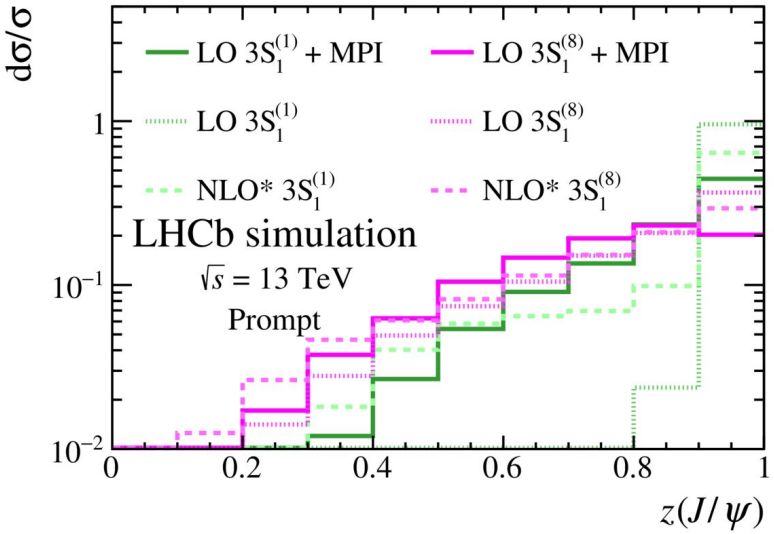
The fragmentation functions are also compared to predictions from Pythia Z+jet events

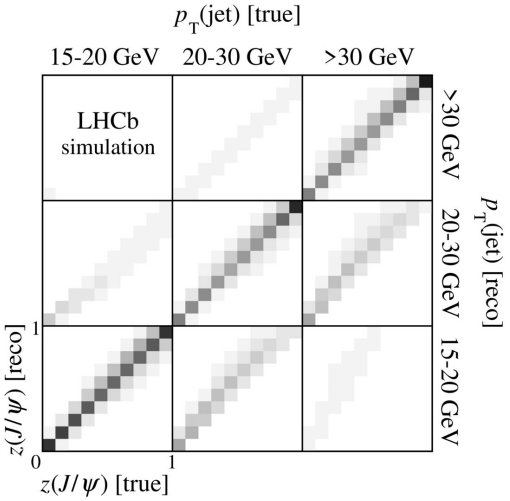
In general, Pythia underestimates the number of charged hadrons at high and low *z* and small *r.* Pythia also underestimates the number of charged hadrons in uniformly in j_T.

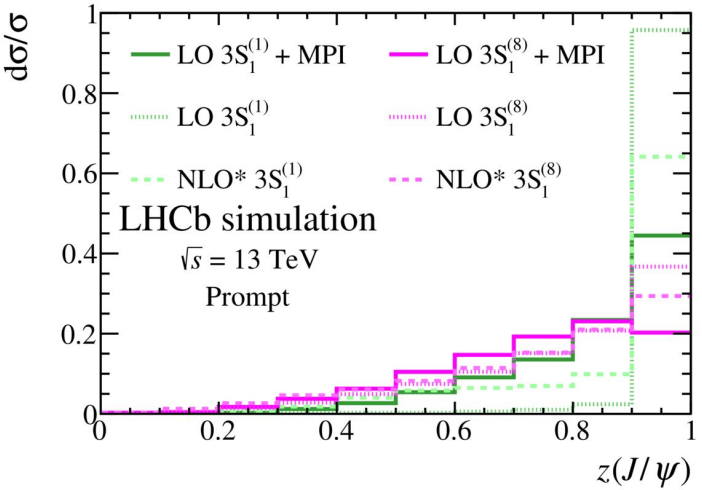
Prompt J/Psi mesons in data are observed to be much less isolated than predicted

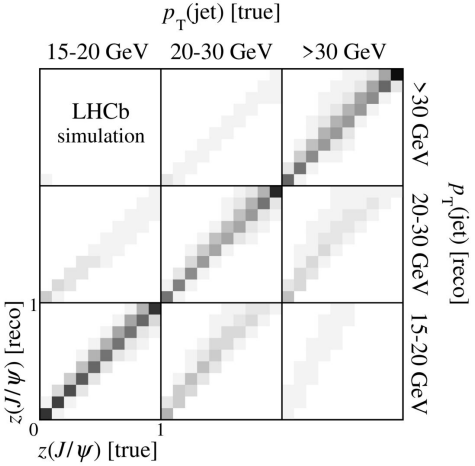
The lack of isolation observed for prompt J/Psi production may be related to the long-standing quarkonium polarization puzzle.

If high-p_T J/y mesons are predominantly produced within parton showers, rather than directly in parton-parton scattering, then the observed lack of both polarization and isolation could be explained.

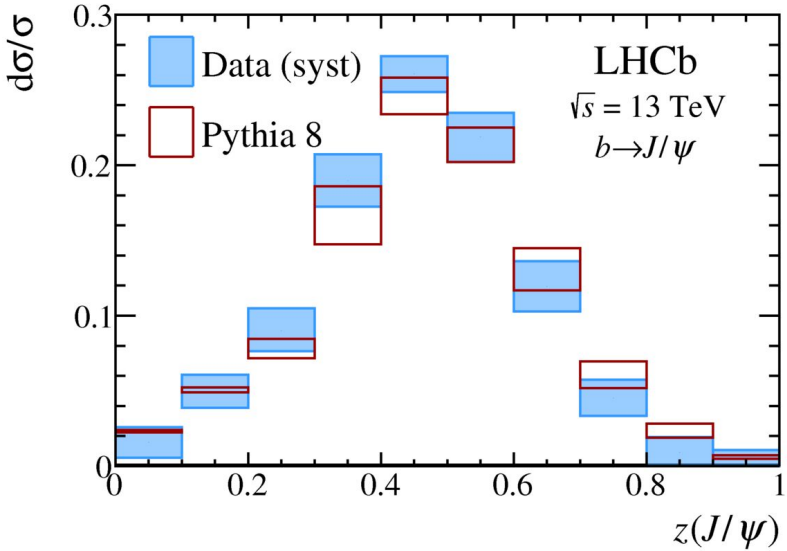

dσ/σ
LO 3S1(1) + MPI
LO 3S1(8) + MPI
LO 3S1(1)
LO 3S1(8)
NLO* 3S1(1)
NLO* 3S1(8)
LHCb simulation
√s = 13 TeV
Prompt
z(J/ψ)

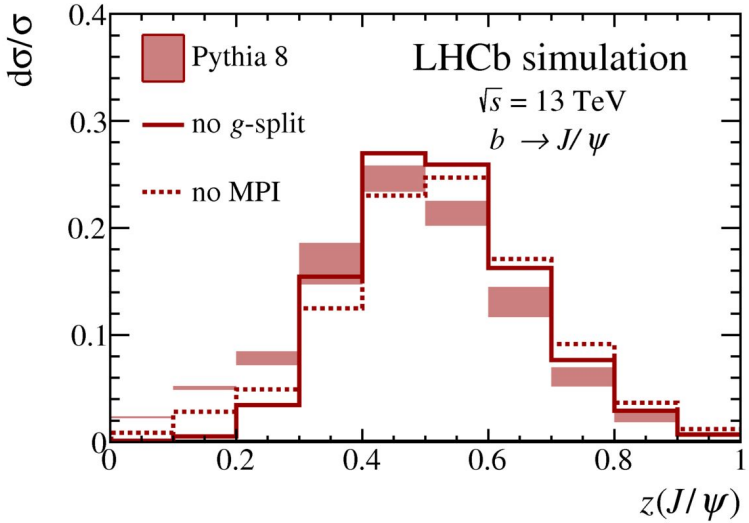

pT(jet) [true]
15-20 GeV
20-30 GeV
>30 GeV
LHCb simulation
pT(jet) [reco]
z(J/ψ) [reco]
z(J/ψ) [true]


dσ/σ
LO 3S1(1) + MPI
LO 3S1(8) + MPI
LO 3S1(1)
LO 3S1(8)
NLO* 3S1(1)
NLO* 3S1(8)
LHCb simulation
√s = 13 TeV
Prompt
z(J/ψ)


pT(jet) [true]
15-20 GeV
20-30 GeV
>30 GeV
LHCb simulation
pT(jet) [reco]
z(J/ψ) [reco]
z(J/ψ) [true]

PRL 118 (2017) 192001





- J/y from b-decays are well described by Pythia8 model
- Hard to discriminate between other parameters

Fragmentation fractions:

- essential for determining absolute branching fractions (ex: $B_s \to \mu\mu$)
- expected dependence on p_T and η

arXiv:1902.06794 [hep-ex]